BILATERAL TENDENCIES AND HABITS IN THE TWENTY-RAYED STARFISH PYCNOPODIA HELIENTHOIDES (STIMPSON).

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CONTENTS.

INTRODUCTION.

The purpose of the investigation upon which this paper is based is to show to what extent the radial symmetry in *Pycnopodia helienthoides* is disturbed by its bilateral tendencies.

The nature of the investigation has been primarily based on observations on the animal in its native home, and as little as possible have conditions been introduced during experimentations which would deviate from that of its natural abode.

The carrying out of this experimental work on *Pycnopodia* was done in connection with other work at the University of Washington, during the year 1915, and during part of the summer of 1916. The experimental work was done at Bremerton, Wash., which is situated about twelve miles from Seattle. In some of

the bays at Bremerton, *Pycnopodia* had congregated in superabundance, offering a considerable inducement to perform experiments on them there, rather than anywhere else on the Puget Sound. And although much time was consumed in traveling between Seattle and Bremerton, the abundance of specimens at the latter place compensated fully for the time thus lost. Occasionally a number of specimens were brought from Bremerton and planted in Elliot Bay at West Seattle for the purpose of studying them there, but when the salinity was found to fluctuate more at the latter place than at the former, it was thought unwise to study them in the new place as under normal conditions and therefore, Bremerton was sélected as the most logical place for collecting these data.

ECOLOGY.

DISTRIBUTION.

Pycnopodia helienthoides is found along the Pacific Coast from central California to southeastern Alaska. It inhabits the entire Laminarian Zone, *i. e.*, from low-water down to a depth of fifty fathoms, or even beyond that. Very seldom is it caught above low-water mark. When thus found, it is generally in pools where the water remains fresh till the tide returns; when found on piles under docks, after the tide has run out, it is because of the fact that *Pycnopodia* does not readily move backward or sidewise, but uses the side established as fore-end, always as anterior end. In places where the bottom is sandy and void of food and where nearby piles are covered with barnacles, *Pycnopodia* may be found, at low-tide, above the water-line. As was clearly demonstrated by some of the samples that were brought to West Seattle and placed under an old dock there, at low-tide a goodly number of them were found hanging on the dry piles. These piles were covered with barnacles and the bottom below was very sandy and depleted of all kinds of food. The writer has never found a duplication of this in other places, however. It may be that the star in this particular instance was exceptionally hungry and did not notice the decreased pressure as the tide receded; in places where food is readily obtained elsewhere, *Pycnopodia*, as a rule, keeps below water.

The Puget Sound region is well suited to *Pycnopodia*. The

temperature, moderate during the entire year, the many sheltered bays and the great abundance of food are undoubtedly contributing factors for the presence of this species of starfish in large numbers. Professor Kincaid, while dredging for marine specimens in connection with work at the Puget Sound Marine Station at Friday Harbor, has come to places where he has got the dredge absolutely full of *Pycnopodia*.

The coast-lines along the shores of the bays at Bremerton, especially along the shores of the town, are literally covered with starfish of various species. The most numerous is the *Evasterias troschelii* (Simpson); then, the species *Piaster ochraceus* (Brandt); *P. paucispinus* and *Dermasterias imbricata* are also found as well as *Pycnopodia*. The numeric ratio of the four former is one *P. ocraceus* to twenty-five *E. troschelii;* one *P. paucispinus* to fifty *E. Troschelii*, and as many *Dermasterias* as *P. ochraceus*. There is a considerable variation in the number of rays of *E. troschelii*. The normal number is of course five, but many have six rays, others seven, and still others four. These species occur in certain belts along the shore, *e. g.*, *Evasterias* occurs the farthest up; in the lower part of this belt, and extending below, is *P. paucispinus*. *P. ochraceus* is seldom found above low-water mark, and together with it are *Dermasterias* and *Pycnopodia*. This may then be taken as the upper limit for *Pycnopodia*, and the lower limit as that as stated before, about fifty fathoms. It is in this respect common with members of the related family Brisingidæ (Sars, 1875), *e. g.*, *Labidiaster radiosus* (Lütken) which, according to Ludwig, occurs in the south Atlantic and south Pacific oceans, in the littoral zone. Verrill, referring to the same species, says: "Unlike the other forms of Brisingidæ, it lives in shallow water as well as at considerable depths. It is found on both coasts of Patagonia and off Cape Horn, etc."

Movements.

Righting Reactions.

When experimenting on righting reactions care was taken so that the specimens would be under as normal conditions as possible, and no restrictions were put on them. A large number of trials were made in nature without taking any data; but the

striking similarity of reactions when disturbed gave cause for recording carefully the actual means and manners of righting. A small specimen from shallow water demonstrated very strikingly when put in a large tub of sea-water that *Pycnopodia* has a marked control of its radial muscles. That is to say, it has greater power of correlation of muscles than perhaps any other starfish. Out of fifty trials on the same specimen, forty-six turns were toward the same side, three turns toward the opposite side, and one turn at right angles. After one becomes familiar with the general method of righting reactions which *Pycnopodia* follows, one can easily notice any other method it may adopt or chance upon in an effort to right itself. It makes no difference as to the direction of the rays of light, the star uses the anterior end, as initiative end, in turning. To illustrate: When this species is turned on its back it immediately commences to put its anterior end under its back (Figs. 1, 2, Plate I.), attaching the sucker-feet to the bottom and pulling with them, while with he opposite end, also curved under, it pushes until the dorsal side is up. To right itself in the direction most usually followed, au unified impulse is apparent as soon as the star has been turned on its back. One may keep experimenting in this way almost indefinitely with the same result as above. The turning over toward the right angle happened perhaps accidentally, in that one ray which was at right angles to the anterior ray caught hold on the bottom first, and the pull begun in that direction, the other rays coöperating, pushing or pulling. Such a turn, however, as seen in the appended table, takes by far much longer time than even the slowest righting reaction toward the posterior or anterior ends. Therefore, when abnormal rightings occur, they are apparently due to fatigue or confusion, as the movements at the beginning of experiments are always in the same direction, provided that the specimens be taken from fresh and tolerably shallow water. Experiments on specimens which had been kept in a vessel for some time, invariably gave fluctuating results; they would act as if unbalanced, a fact undoubtedly due to the deoxygenation of the water. Other factors, external and internal enter in also. Externally there is the change in temperature as well as the depletion of oxygen; internally there is the effect of

external conditions. The lack of oxygen, or the insufficient amount of it causes, as demonstrated by Loeb (6) and others, ". . . at first molecular, and later morphological changes in the cells, which in turn are the cause of the supension of life-phenomenon." No apparent morphological changes were observed on the star from the lack of oxygen, but the unbalanced behavior seems to indicate some changes to have taken place. The effect of the stimuli received from the righting impulse, whether it be a normal or an abnormal individual, is to move away from the place of disturbance. (Fig. 3, Plate I).

Such definite movements tend to show that *Pycnopodia* has some established habits. In this respect it is indeed very much different from the common starfish, *e. g.*, *Asterias forbesi* and *A. vulgaris*, which, according to Dr. Coe (2), "Do the same thing, under the same conditions, in a number of different ways, and never do the same thing twice in exactly the same way."

Jennings (4) also makes a statement similar to that of Dr. Coe, when he says: "The starfish (*Asterias firreri*) is not hampered by any consideration of anterior or posterior; it may move with any of its rays in the lead, or with any interradius in advance, or indeed in any intermediate direction, so that its possibilities as to direction of locomotion are really unlimited. In the same way, it may right itself in an indefinite number of different ways." *Pycnopodia*, however, has already formed certain definite modes of behavior. Part of these is indicated by its righting reactions. The speed of righting, as seen below, is not improved by repetition, but the method of righting indicates clearly that it possesses a more definite control of its muscles, or has a more definite method of righting itself than has the common starfish. In regard to habit formation the result is negative.

Jennings (4), in describing the righting reactions of the common starfish, says: "After repeated experiences by a given individual, there was no improvement in the performance of this reaction, either in the time taken, or in the movements employed in accomplishing the righting."

The first eleven trials show uniformity in speed of righting reaction; the first three show the same speed. Then there is a very rapid turn, taking only half the time of one of the previous

RATE OF RIGHTING REACTIONS: Experiments carried out on April 4th, 1915. Temperature 10° C.

Number of Trials.	*Time.*	
1st trial	60 sec	The first 20 trials are in the same direction, *e. g.*, toward the anterior end. The average speed of righting in these trials equals 66 sec.
2d "	60 "	
3d "	60 "	
4th "	30 "	
5th "	50 "	
6th "	60 "	
7th "	40 "	
8th "	40 "	
9th "	40 "	
10th "	60 "	
11th "	70 "	
12th "	70 "	
13th "	70 "	
14th "	65 "	
15th "	70 "	
16th "	65 "	
17th "	75 "	
18th "	85 "	
19th "	110 "	
20th "	120 "	
21st "	70 "	Righting movements toward posterior end.
22d "	50 "	Righting movements toward the anterior end. The average speed equals 55 sec.
23d "	50 "	
24th "	55 "	
25th "	60 "	
26th "	60 "	
27th "	50 "	
28th "	40 "	
29th "	40 "	
30th "	60 "	
31st "	90 "	
32d "	70 "	Righting movement toward posterior end.
33d "	40 "	Righting movements toward the anterior end. The average speed equals 52.7 sec.
34th "	30 "	
35th "	30 "	
36th "	40 "	
37th "	40 "	
38th "	44 "	
39th "	50 "	
40th "	55 "	
41st "	60 "	
42d "	60 "	
43d "	65 "	
44th "	65 "	
45th "	70 "	
46th "	90 "	

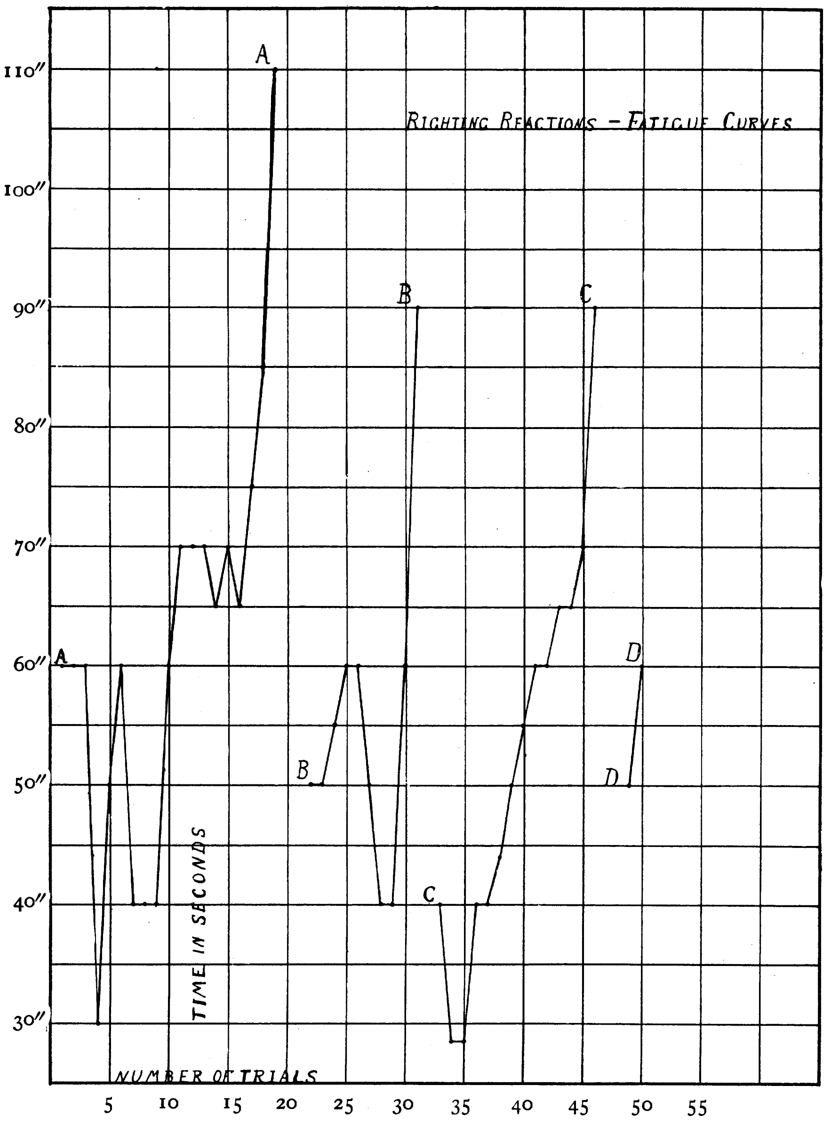
47th "	.... 80 "	}	Righting movement toward the posterior end.
48th "	............180 "	}	Abnormal turn toward right angle of anterio-posterio ends.
49th "	.... 50 "	}	Righting movements toward anterior end.
50th "	.... 60 "	}	The average speed equals 55 sec.

The total average speed of the normal turns equals 57.1 sec.

trials. At this point the writer thought that the star was learning to do the righting more quickly than at first, but the subsequent trials disprove it. After this last trial, three of equal speed follow, each taking only 40 sec., but after these there is a slowing up in speed, an indication of fatigue. The speed is now gradually diminished until at the twentieth trial, when it takes two minutes in righting itself. Following this is a righting toward the opposite side, at a speed of 70 sec., but the succeeding ten trials are all again in the same direction as at first, and with an average speed of 55 sec., per righting. Then follows another turn toward the posterior end, with a speed of 70 sec. This is followed by fourteen turns toward the anterior end with an average speed of 52.7 sec. Now follows the abnormal turn described above, a turn toward the right side, with a speed of three minutes, followed by two turns toward the anterior end with an average speed of 55 sec. per righting. Here ends the experimenting on right movements on this particular individual. The total average speed per normal rightings is 57.1 sec. per righting. The series of rightings in one direction indicate fatigue toward the last, or a decrease in speed of righting; a turn toward the posterior end is followed by an increased speed in the succeeding rightings toward the anterior end, which, however, soon decreases. Whatever this may indicate, one thing is apparent: that *Pycnopodia* is able to right itself in more than one way, but that it turns more easily and far more frequently toward the anterior than toward the posterior end; that it never turns twice in succession toward the posterior end.

These trials on righting reactions were made on a small individual of four inches in diameter, and which had 13 rays. This specimen was kept in a cage of six by four by one feet in size. The cage consisted of a wire-aquarium which was anchored to a

FIG. 1.


RIGHTING REACTIONS – FATIGUE CURVES
110″
100″
90″
80″
70″
60″
50″
40″
30″
TIME IN SECONDS
NUMBER OF TRIALS
5
10
15
20
25
30
35
40
45
50
55
A
B
C
D

float. The specimen was fed on small shell-fish of the families Cardiidæ and Leptonidæ; on gasteropods: *Amphissa versicolor* and also on crabs (*Pugettia gracilis, Cancer orgonensis*). Subsequent experimenting with this specimen showed the same general results. When using mature specimens the same general phenomenon was observed.

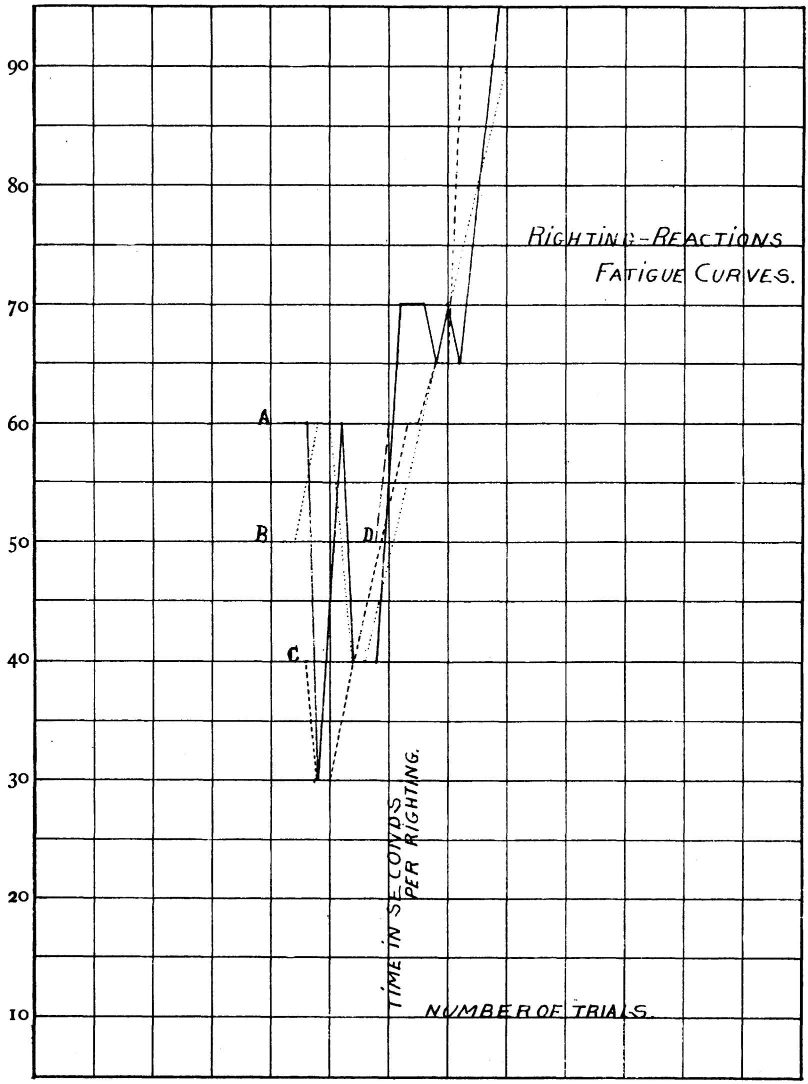
The righting reactions may be represented by curves which may show the whole working of fifty trials of righting. These curves also show the indication of fatigue, and are, therefore, called righting reaction-fatigue curves (Fig. 1). The abnormal or confused rightings are omitted from curves, hence the break between the respective curves. The number of trials are plotted on the abscissa. The speed in righting reaction is indicated by squares on the ordinates which in turn stand for minutes. Curve *AA* equals trials 1–19 (the twentieth trial omitted in figure); curve *BB* equals trials 22–31; curve *CC* equals trials 33–46; curve *DD* equals trials 49–50.

These curves when superimposed show an interesting figure (Fig. 2). There is the same picture as in Fig. 1, an indication of fatigue, toward the last. However, curve *AA* has an average reaction speed of 66 seconds per righting; curve *BB* has an average reaction speed of 55 seconds per righting; curve *CC* has an average reaction speed of 52.7 seconds per righting. This shows that the speed per average reaction is increased after each turn toward the posterior end, and that may indeed count for the difference in increase of speed in the turnings toward the anterior end, that is, it becomes easier to turn toward the anterior end after it has tried to right itself in some other direction.

Tidal Movements.

Pycnopodia moves rapidly enough so as not to be caught by the outgoing tide. Its success in this regard is partly due to its habit, partly because of its physical need to be submerged, and it has therefore developed a speed of movements great enough to enable it to keep submerged all the time. During high-water it may move a considerable distance above low-water mark, and during such time be found on grounds which will be dry at low-water. In such cases it will move a little ahead of the tide,

FIG. 2.

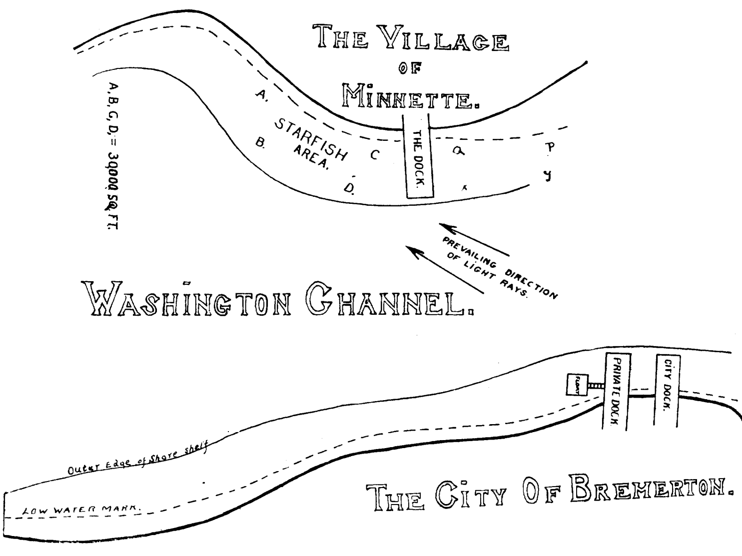

90
80
70
60
50
40
30
20
10
A
B
C
D
RIGHTING-REACTIONS
FATIGUE CURVES.
TIME IN SECONDS
PER RIGHTING.
NUMBER OF TRIALS.

as the tide runs out. The rate of speed of such distance-movements depends on the circumstances. For example, when instigated to move by some artificial means, as by being turned on its back, brought from deep water to shallow water, the rate was 2.5 feet per minute. When, however, during tidal recession it would remain stationary on its temporary feeding ground, selected during high-tide, until the water measured about 2.75 feet. Then it would begin to move down to deeper water, continuing moving until it had reached a depth of about 4.5 feet, and at a rate of 3.5 feet per minute. This shows that when instigated to move by a natural stimulation its rate of speed is greater than when caused to move artificially.

Irritability Limit.

Another indication brought out in this connection is that *Pycnopodia* is sufficiently sensitive to pressure so as to start

FIG. 3.



moving down to deeper water when the tide has receded to a certain level. As a matter of fact, out of seventy-five specimens that were examined during one low-tide on a given area (Fig. 3), only two were at the shallow depth of 2.5 feet. Specimens brought from deeper water to shallower water, that is from any

depth (see topic on distribution, p. 233) to a depth of about three feet, will move down to a depth of at least five feet. Then the irritability limit ranges between the pressure of 2.5 feet and 5 feet of sea water. The average depth of the 75 specimens referred to above, on an area of about 30,000 square feet, was 4.76 feet. The minimum pressure in this irritability limit, to which *Pycnopodia* is adapted, is seen to be about 1.13 lb. to the square inch.

An irritability limit may seem improbable when it is considered that this starfish has been found on piles above water and on dry tide-flats during low-tide. Either of these cases is very extraordinary, in that tidal recession on tide-flats is sometimes great enough even to catch swiftly swimming fishes. On piles onto which the gluttonous starfish has been lured by the presence of barnacles, the tidal recession is indeed the slowest possible, but in this case the star is in a very awkward position to move. It has already been stated that the righting movements are almost invariably toward the same side. This is also the case relative to distance-movements. One end is, much more so, than in any other starfish, the anterior end; *Pycnopodia* has a decided bilaterality in this regard. That is, it is used to move with the same side as anterior end.

When it moves the rays are curved at the ends, the eye-spots wide open. The second pair of primary posterior rays is pulling along with the odd posterior primary ray; the sucker-feet are engaged in a lively and continuous march. The third pair of primary posterior rays is occasionally lifted foreward spontaneously, while the first pair of the post-larvel rays which is at right angle to the anterio-posterior rays, when the star is at rest, is lagging somewhat behind. During such movements, this anterior end is decidedly used as such, so that when the star encounters obstacles which it may not crawl under or over, it merely, as an ordinary bilateral animal, turns toward its right or left side. It does not, in such instances, utilize its radial symmetry by starting to move backward or to the right angle or to any other angle to its longitudinal axis.

Migratory Movements.

Statements have already been made to the point that *Pycnopodia* possesses locomotive powers great enough so as not to be caught by the outgoing tide, provided that the land is not too flat. The rate of tidal recession, even during times of extreme low-tide, will not be faster on a slope of six inches to the distance of twelve and a half feet, than *Pycnopodia* is able to keep pace with. In addition to these kinds of movements which have been mentioned, *Pycnopodia* seems to move according to seasons of the year. Seasonal movements, as they may be called, have three underlying primary causes, to wit: reaction toward light, search for food, and the breeding impulse. These three are causes for extensive migrations.

Reaction toward Light.—During the summer time *Pycnopodia* is found, as a rule, in deeper waters. If found in shallow water during this time of the year it will almost always be in shaded places, as under docks, under kelp, algæ or on the shaded side of a bay. This seems to point to negative heliotropism. In the spring, 1915, during the breeding season, *Pycnopodia* was found actually congregated in large numbers on the sunny side of the bay, but two months later there was not a single specimen on that side of the bay, while on the shaded side of the same bay a few were found under a dock, but farther out than during the spring and winter. Movements of this nature vary, however. As was seen during the summer of 1916, when the whole summer was exceptionally rainy, cloudy and cool, *Pycnopodia* seemed to take advantage of such conditions and remained in shallow water all the time. August, however, proved to be more sunny and warm than the early part of the summer, with the effect that the rays of the sun became annoying to the star. This unexpected and intense light caused every single specimen, as far as could be observed, to move away, either down to deeper water or to hide under some object. The dock, as an illustration (Fig. 3, Minette side of the bay, starfish area *ACBD*), served as a satisfactory shading place, where *Pycnopodia* actually congregated in a continuous layer from three feet depth to as far as could be seen at low-water. The question arises: How did the star find the dock to hide under when the sunny days of August suddenly came?

The dock, as seen in Fig. 3, is located near the point of the Minette side of Washington Channel, opposite the City of Bremerton. On no occasion has the writer observed *Pycnopodia* on the outside of the dock or in the area *QPXY*, but always on the inner side, toward the Washington Channel. The sudden continuous sunshine which came in August with the temperature the highest in the year soon made itself felt to the negative heliotropic star. Observation on the direction of the rays of light during the middle of the day explains this phenomenon. The light rays of the late forenoon and early afternoon are up the channel, or diagonally from the dock toward the starfish field, *ACBD*. The cause for the movements and orientation of the star in this particular case must be sought in the phenomenon of the effect of the direction of the most intense rays of light.

Loeb (6), working on *Spirographis spallanzanii*, found that rays of light, if sufficiently intense, are unequivocally able to determine the orientation. In summarizing the causes for moving to or from the source of light, he says: "The direction of the median plane of an animal coincides with the direction of the rays of light. Light of a constant intensity acts as a constant stimulus, in animals as well as in plants." These statements seem to explain why *Pycnopodia* "found" the dock. The star, however, moved toward the source of light, and according to Loeb's conception of the behavior of heliotropic animals, that should make *Pycnopodia* positively heliotropic, for, "Positively heliotropic animals will move toward the source of light, even if in so doing they go from places of greater intensity of light to places of less intensity." When the star, however, came under a good shading object, such as the dock offered, it remained there for several weeks, and did not venture away from the dock in either direction.

As was said above, *Pycnopodia* occurs in shallow water during the spring and late winter, and in deep water during the lightest part of the year. The early part of summer and late part of winter are the regular migratory periods. The causes for migratory impulses have been designated as three: the effect of the rays of light, search for food and the breeding impulse. But in a rather large number of cases movements of *Pycnopodia* at the

two stated periods may not be effected by any one of these causes, separately. For still other factors enter it, and, therefore, more frequently several causes may coöperate, resulting in definite movements at the same time. Thus the variable conditions within the animal may cause different reactions toward light at various times.

Loeb (6) has shown that the caterpillars of *Porthesia chrysorrhœa*, after fasting through the winter, are energetically positively heliotropic; but that after these animals have eaten, heliotropism is not shown so definitely Plant lice become positively heliotropic only after they have fed; the larvæ *Musea vomitoria* are energetically negatively heliotropic only when fully grown, etc.

Heliotropism in *Pycnopodia* is, however, only a partial cause for migration or distance-movements, and the periods of migration are not very definitely marked; they are quite extended in time. Various external conditions, as well as internal, contribute to this.

Search for Food.—The food problem is another factor which determines the distance-movements in *Pycnopodia*. It will, like other starfish, move according to the distribution of food. If *Pycnopodia* finds its surroundings scarce in food material, it has no difficulty in taking leave for different grounds. In fact, as it has been found in bays at a depth of twenty fathoms where there would be a great variety of food, *e. g.*, sea-urchins (*Strongylocentrotus dröbaciencis*), *Pectens*, *Yoldia*, etc., when conditions for it would not be favorable to remain on other grounds, such as in shallow water during the summer, indications seem to point that way.

Breeding Impulse.—Temperature together with the impulse to breed are still other causes for migration. The temperature below ten fathoms is comparatively constant during the entire year, while the temperature at the surface varies quite considerable during the year. The lowest and highest temperatures during the year 1915 were 9° C. and 16° C. respectively. That *Pycnopodia* should move up to shallow water during the spawning season seems reasonable, for the temperature in deeper waters is undoubtedly lower than at the surface even during the spring. Reference was made

above to the fact that *Pycnopodia* was found in large numbers on a certain side of a bay, during spring, while it was totally absent from these grounds later on, during the summer. As a matter of fact, during the spring of 1915, on the area *ACBD* (Fig. 3) more than one hundred specimens were counted, while in July of the same year not a single specimen was seen on the same area. The change in habitat was perhaps due to the intense sunlight, as during the cool and rainy summer of 1916, a large number was seen on the same area until constant sunny weather ensued. As demonstrated above, this is an indication of positive heliotropism. The habitat of *Pycnopodia* ranges over the entire belt of the laminarian *Benthos;* it lives as a rule in deeper water during the warm and light part of the year, and in shallower water during the spawning season and during the darker and colder part of the year.

Feeding.

Kinds of Food.

The feeding habit of *Pycnopodia* is striking and very interesting indeed. It lives on such types of mollusks as clams and gasterpods; on crustaceans, such as crabs and barnacles; on other echinoderms, such as common starfish and sea-urchins; on porifera, and on algæ.

Methods of Feeding.

The methods of feeding are by engulfing and sucking. Large rocks up to a pound in weight have been found in the stomach. These were engulfed when sucking on barnacles, because markings of barnacles could be seen on the rocks. The large horse clam (*Schizothærus nauttalli*) cannot be engulfed on account of its enormous size. But when *Pycnopodia* encounters *Schizothærus*, it rolls itself around the latter and proceeds to digest it. On one occasion the writer found the star in the act of consuming one of these large horse clams. The extraordinary large syphon was forced into the mouth of the starfish while the everted stomach was folded around the syphon. The whole star had in fact, rolled itself around the clam, endeavoring to pull it open. This pulling on the part of the star had, however, no effect on the clam, for, although the latter might have relaxed to the continuous pull of the sucker-feet, it was of no avail because the folds

of the stomach of the star could not reach the vital parts of the clam exposed by the relaxation of the adductor muscles. The reason for the failure to kill the clam was due to the fact that the syphon of the clam, as stated before, was extended into the mouth of the star. The star seemed to have no effect on the clam, except that the syphon was partly digested around the edges of its apertures. Otherwise the clam seemed to have enjoyed the gastric juices of the star; it was still alive and behaved like unmolested clams of the same kind, when it was freed from its pursuer. Small clams are more easily preyed upon. Ordinary cockles are as a rule engulfed. In opening cockles or smaller clams, *Pycnopodia* holds its prey until it has a chance to force some of its everted stomach into the shell-fish, and having succeeded partly in this respect, it digests its prey piecemeal. In other instances, members of the family Natidæ (*e. g.*, *Nassa mendica*) were found in the stomach of this starfish, together with egg-bodies of Natidæ. As a matter of fact, *Pycnopodia* feeds especially on gasteropods, engulfing the smaller ones, as in the case of the last referred to. *Polynices*, though a monster of a slug, is a very easy prey, indeed, to *Pycnopodia*. In fact few, of this slug are found on grounds common to *Pycnopodia*. From experiment it was found that *Polynices* is very sensitive to the surface of this star. When keeping several *Polynices* in the aquarium with one *Pycnopodia*, it was found that the latter devoured three large (foot, about 8 inches long, 5 inches wide, and 4 inches deep) specimens in three days, leaving the shells on the outside. The method of feeding on these slugs is simply by suffocation. The slug seems to be incapable of living very long within its shell, and unless it is allowed to take in fresh water, when relaxing, it soon has to come out as a mere powerless, defenseless matter of flesh. When, therefore, *Pycnopodia* has *Polynices* in its control, the latter must very shortly give in to the former. In still other instances, remnants of crabs were found in the stomach of this star also. In this connection, experiments on feeding it with crabs were actually performed. Having stabbed a crab (*Magister productus*), it was thrown into the water so that it would fall down beside or on the top of the star. In one such instance, the latter seized the crab-fragments

with its pedicellariæ and crawled away with it to deeper water, and then started to feed on it there. In another instance, the star started to feed on the dead crab at once. In so doing it put the rays over the crab, tucking it under itself, rising on the tips of its rays and in this way proceeded to devour its meal. In yet another instance it was found that *Pycnopodia* was feeding on other starfish (*Evasterias troscehlii*), and this even though there seemed to be plenty of gasteropods and other mollusks present. It was also found to be feeding on *Strongylocentrotus dröbachiensis*. Finally *Pycnopodia* feeds on porifera and on plants—of the latter, kelps and algæ. This last kind of food is probably resorted to when clams and gasteropods are beyond its reach. Because of these various types of food that this starfish feeds on, it may well be said that *Pycnopodia* is omnivorous in its habits of feeding.

Conclusion on Movements in General.

The fact that *Pycnopodia* always moves along one and the same axis, with the same side always as anterior end; the fact that it has a definite method of righting itself, as well as apparent voluntary behavior during feeding, seems to point to dominating bilateral symmetry rather than radial symmetry. With such evidence of dominating bilateral symmetry, one should expect a nervous system more complex than that of the ordinary starfish. Indeed, something relative to experiments on the regenerative powers of this genus seems to point that way. The regenerative powers in *Pycnopodia* seems to be less than in the common starfish.

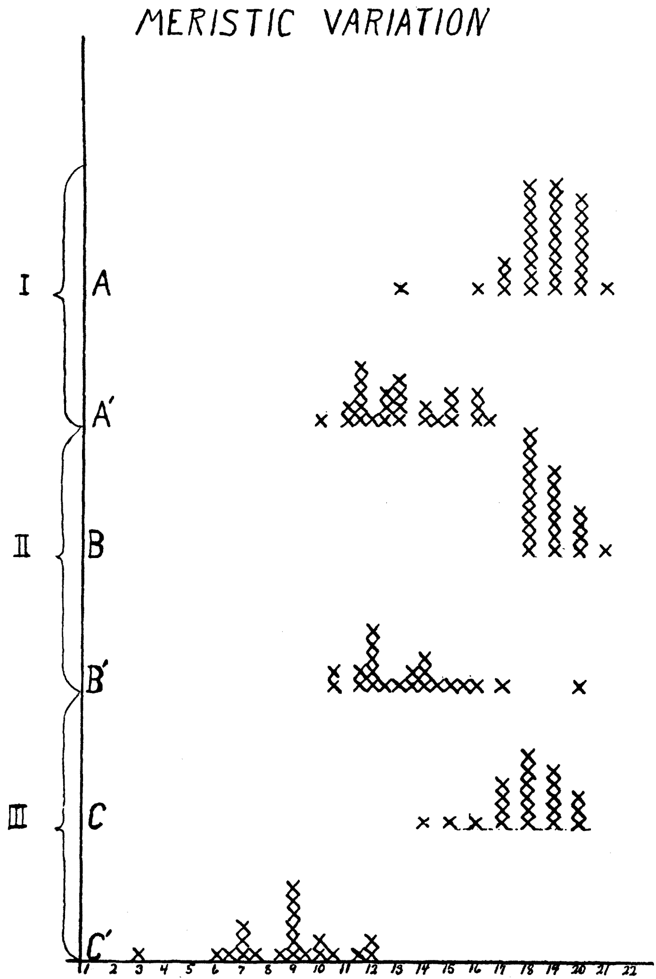
Meristic Variation.

The Modal Curve.

The modal point of rays in males, females and immature specimens is represented in Fig. 4. That of the female, *IIBB′* shows an abrupt demarcation, in that the average modal point of number of rays is reached before maturity, while that of the male fluctuates. This fluctuation, however, is the same after the modal point is reached, but is of course greatest, regardless of sex, among the immature, although that particular number which was examined showed a modal point much the same as that of the mature ones (Fig. 4, *IAA′*, males; *IIICC′*,

immatures). This was no doubt due to the fact that only a few small ones were found, and those found were approaching maturity. Curves representing the diameter may also be plotted (Fig. 4, *A'B'C'*). In each case the diameter which is measured

FIG. 4.



in inches from tip to tip of rays along the median axis is plotted on the abscissas, the number of specimens on the ordinates.

Ritter and Crocker (9) states that out of one hundred specimens that they studied not one was of the 18-rayed stage. Here, how-

ever, the modal point in both the male and female is seen to be 18. The adult cannot be determined by the number of rays, because the immature star may reach the modal point in number of rays, and like mature specimens go beyond the modal point, and even not reach maturity, while on the other hand mature male specimens may be found to have only 13 rays, which is reaching down into the immaturity limit. Mature specimens spoken of here have special reference to sexual maturity for that season. The modal point of both males and females is practically the same.

This is demonstrated by a number of specimens examined in the same region on the same day, and represented by Fig. 4, *I*, *A* (male), *II*, *B* (female). As a matter of fact, the average number of rays in the male, female and immature is almost the same, which goes to show that radial development occurs in the comparatively early part of the life of the individual star. On this occasion, the depth for and the diameter of every specimen was measured; and the number of rays present, and the sex was determined. These findings were as follows:

1. The average depth at low-tide for 75 specimens found in a belt 30 feet wide by $\frac{1}{5}$ of a mile long was 4.76 feet.

2. The diameter measured along the median axis from tip to tip of odd anterior and odd posterior rays for immature was 8.21 inches, and the average number of rays was 17.85.

3. The average diameter of the males was 13.5 inches, and the average number of rays was 18.56.

4. The average diameter of the female was 13.6 inches; the average number of rays was 18.8.

SUMMARY.

1. *Pycnopodia* is highly bilateral when moving about in its natural abode. It uses the same side always as anterior end.

2. During righting reactions, this same side almost always takes the initiative and the greatest number of rightings are made in that direction. Repeated rightings do not improve its speed.

3. It is hardly ever found on dry land; its movements are swift enough so that it keeps below the tidal mark; it moves swiftest when stimulated from within.

4. In this, it seems to be partly governed by its sense to the pressure of minimum depths.

5. Three prime causes effect its migratory habits, to wit: (1) sensitivity to light of a certain intensity; (2) search for food; and (3) the breeding impulse. During the breeding season it is neither negative nor positive heliotropic; for it moves up from deeper water to shallower water independently of the directions of the rays of light. After spawning, however, it seems to be positive heliotropic.

6. It is omnivorous; it is carnivorous. It feeds mainly on Gasteropoda, but also on Pelecypoda, other species of starfish, sea-urchins, crabs, sponges, kelps and algæ.

7. The female seems to have reached a more definite number of rays before maturity, than has the male (see Fig. 4).

8. Maturity is not entirely dependent on the size of the animal; *i.e.*, the diameter varies: In immature up to 12 inches; in males from 10–16½ inches; in females from 10½–20 inches. The females are on the average larger than are the males.

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Explanation to Plate I.

Figs. 1–3. Photos of *Pycnopodia helienthoides* (Stimpson), showing righting movements; Fig. 1 shows the ventral side, and the beginning of righting. Note the outstretching tube-feet; Fig. 2 shows the same specimen ten seconds later, almost semi-righted: Fig. 3 shows the righted specimen, just after righting active y moving along. $\frac{1}{7}$ natural size.

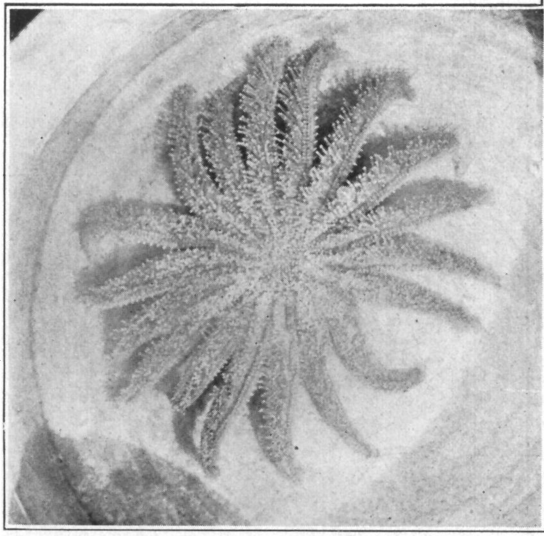

FIG. 1.

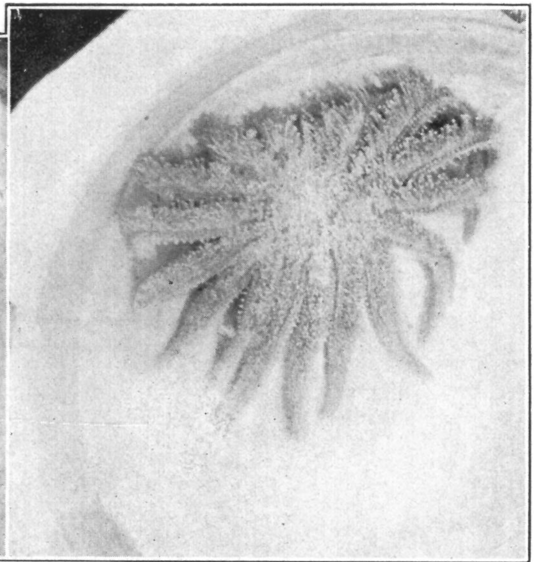

FIG. 2.

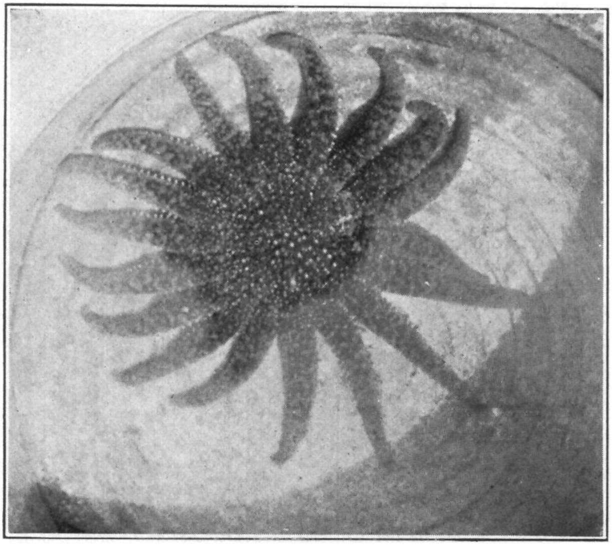

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FIG. 3.